Overview of Indoor Plants: Phytoarchitecture as A Building Health Platform

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Decorative plants have developed into a strategic position in an effort to healthy indoor buildings, adding to their functions as decorations for the comfort of occupants. This overview of decorative plants aims to describe the determining factors in the relationship between plants, humans, phytoremediation, to produce sustainable healthy indoor quality. The literature searches and selection method used the Mendeley Reference Manager platform. The results were categorized as interactions between plant and human responses, and between plants and indoor environmental quality. In summary, decorative plants are able to make people of all ages and their activities healthy physically and mentally, and it is important to avoid toxic plants even though they look beautiful. The ability of plants has been proven to be able to improve the environmental quality of indoor pollutants, as a function of phytoremediation to make indoor healthy for sustainable use, although should avoid plants with negative effect properties. The status is convincing to make decorative plants an essential living element in indoor. Promotion strategies and implementation tactics are proposed, adapted to local conditions.

Keywords: decorative plants, human response, people preference, phytoremediation, progress status, implementation

1. INTRODUCTION

The definition of architecture which is closely related to environmental quality is *"the art of composing and realizing all public and private buildings. For a building to be appropriate, it must be solid, healthy, and comfortable"* (MCH, 2019; Curl, 2006). The definition of architecture puts a high priority on environmental quality for long-term use and with the aim of sustaining its use in a healthy and comfortable manner.

The environment for long time use is indoor, where under normal conditions, people spend about 80-90% of the time (Pichlhöfer et al., 2021; Kapalo et al., 2018; Cetin & Sevik, 2016; Su & Lin, 2015) in any indoor indoor environment. In special cases, the time to stay indoors is getting longer during the COVID-19 pandemic. Indoor has air quality variability between one building and another due to differences in building materials, indoor volume, air exchange, and others. Hence, people experience exposure to different indoor air qualities for long periods of time throughout the day.

Indoor content generally consists of various physical forms, such as furniture, and various forms of life, such as decorative plants, besides of course people. All indoor building materials and contents can be a source of pollution. Indoor pollution through maintenance of cleanliness may not be sufficient, therefore intervention using the ability of decorative plants is needed. Architectural design for indoor air quality management has involved the role of decorative plants (H. Samudro & Mangkoedihardjo, 2021; Oberti & Plantamura, 2017) to eliminate pollutants that arise in indoor activities. So far, the positive impact of using indoor plants has been well tested (Buyun et al., 2020; Zorić et al., 2019), even aeroponic has started trending in its application (Eldridge et al., 2020).

In response to the advancement of the role of indoor decorative plants, a new definition is proposed as indoor phytoarchitecture, viz. the empowerment of plants for the management and processing of indoor quality of a building. The existence of plants is not only a decoration, but also a part of the indoor living structure in addition to other living things, which are capable of processing indoor qualities. In this function, a comprehensive and objective understanding framework is needed regarding the effect of indoor decorative plants on residents and their phytoremediation capabilities. The purpose of this study is to describe the important factors that influence each other between the tricomponent of plants, humans, phytoremediation, in an indoor building, which can run in a sustainable manner. Outcomes of this understanding can be a strategy for implementing phytoarchitecture through architectural design of buildings and the application of decorative plants in various places of activity according to local conditions.

2. MATERIALS AND METHODS

The literature is collected from the Mendeley Reference Manager using keywords: “human response”,” indoor air quality”, “indoor plant”, “indoor phytoremediation”. The results show that there are the oldest publications in 2013 and the newest in 2021. The next literature selection used a checklist screening of journal document types and open access types, and the results were 950 articles. Next is a collection of articles published every year with a screening covering English, articles from empirical research, and the word plants or plants indicating living plants, not infrastructure such as electric power, gas, processing, and others. Based on the selection and screening criteria, 350 articles were obtained, but only 104 articles were closely related to the focus of the study of human response and indoor phytoremediation.

3. RESULTS

3.1. Student response

Schools in South Korea are assessed for the potential for sick school syndrome, viz. indoor air quality conditions that have the potential to cause illness for residents. Observations were made using the school treatment without plants and with plants. Indoor air quality uses formaldehyde parameters, which can arise from building materials and furniture inside. At the beginning, both school treatments experienced a decrease in the concentration of formaldehyde, which was due to the time factor. However, after 3 months later, schools without plants had higher concentrations of formaldehyde than schools using plants. School students, where plants were present, generally did not complain about the presence of indoor plants, and had no complaints related to mental or physical health, such as sensory eye irritation (H. Kim et al., 2016; H.-H. Kim et al., 2013) and students pay more attention (H.-H. Kim et al., 2020). Students in South Korea feel comfortable, relaxed, without emotional when they are in greening activities (A.-Y. Lee et al., 2021). The presence of indoor plants has an effect on the positive attitudes of high school students in Turkey (Selvi et al., 2021), also found in students in the Netherlands (van den Bogerd et al., 2021). The tendency of a biophilic lifestyle among students living in apartments in Surabaya, Indonesia, shows that there are positive benefits for physical and psychological comfort (Prayogi & Yazid, 2021).

In Malaya, students are able to improve their learning performance in a classroom filled with plants, because the room is comfortable at room temperature and refreshing (Jamaludin et al., 2017). The results were extended to a school in Romania, which provides students with nature education in the form of planting plants in schools. Physical and mental activities for children are directed to those who are experienced in school-based greening, both indoors and outdoors. Gardening experience can develop teamwork, affective, sociable, permanent care, and responsibility. Individually, the presence of decorative plants in the room can have an influence on the physical and mental development of children. These factors further increase their level of creativity (Buru et al., 2019).

With regard to preference, a personal preference without environmental influences, was studied for students at a university in the Netherlands. There are more students, who want the greening of the campus than the enrichment of posters. The greenery includes various placements as indoor, wall, facade, and outdoor (Bogerd et al., 2018). The preferences are the same for school students, who want decorative plants in the classroom (van den Bogerd et al., 2020).

3.2 Worker response

Research foliage plant preferences and work in an office in South Korea. *Anthurium andraeanum* cv. is the most preferred among the choices of other types of plants. The most preferred leaf color of the foliage is because it is green. Green leaves are believed to have the effect of stress relief, emotional relaxation, and psychological stability for employees (H. S. Jang et al., 2018). Meanwhile, the preference of indoor flowering plants is shown by people in Taiwan (Lin et al., 2021). There is an interesting sign, that people are able to feel the presence or absence of symptoms of indoor air pollution with the presence or absence of plants (Moya et al., 2021).

For office workers in Indonesia, their perception of the presence of decorative plants *Sansevieria trifasciata* and *Scindapsus sp* is assessed to reduce noise. Two offices with and without plants were measured for noise levels, indicating lower levels for spaces with plants, and employees preferring areas with plants (Mediastika & Binarti, 2013). The placement of leafy decorative plants in the workspace has the effect of keeping the room temperature stable, which is comfortable for employees in Japan (Kurazumi et al., 2017, 2018).

An office in Denmark places decorative plants as a component of the interior of the space, which enriches the diversity of the work environment. The type and placement of plants is adjusted to the traditions, values, culture, history, and policies of the workplace organization. Plant-rich environmental conditions affect the image of the work environment and the physical and mental well-being of employees (Husti et al., 2015). Correspondingly, in Romanian offices, employees are able to increase work productivity both overall and individual workers. The data obtained shows and complements the results of other research on the importance of having natural elements in the workplace for employees and companies (Mariana et al., 2015).

Also in Italian offices, the placement of decorative plants can reduce stress on employees, be sensitive to the environment, and even reduce energy consumption (Oberti & Plantamura, 2017). Similarly, the results of improved mental health and less fatigue were obtained for work related to electronic use and office workers in Japan (Genjo et al., 2019).

Research on the effects of indoor flowering plants for patients with coronary heart disease, which is usually accompanied by secondary effects of depression and anxiety, shows that symptoms of depression and anxiety can be suppressed, thereby accelerating recovery from the main disease (Koh et al., 2017). Similar results were also provided by other hospitals, which showed a reduction in allergy and allergy symptoms for hospital health workers, and pediatric asthmatic patients alike (Y. W. Lee et al., 2017). Elderly patients can reduce their functional decline with the presence of decorative plants (Berg et al., 2021). Especially in mental hospitals in Japan, the presence of decorative plants significantly reduces stress and increases work productivity for health workers (Genjo et al., 2018).

3.3 People preference

For people in housing activities in Bangladesh, they have a preference for intensifying greening of the house, both indoor and outdoor decorative plants (Islam et al., 2020). The existence of house plants for the function of herbal healing can be a positive medium on the intensity of the relationship between parents and children (Y. K. Kim et al., 2020). Placement of aromatic plants at home in China contributes to comfort and emotional calm for the elderly (Hua et al., 2020) and school students (Jiang et al., 2021). Herbal, colourful and scented plants are preferred by firefighters in South Korea (H. S. Jang et al., 2020). The preference for greening office buildings, hotels and other busy places, is also an increasing trend in Ukraine (Kosenko et al., 2020) and in restaurants in Turkey (Hidayetoğlu et al., 2020).

In several places, homes, schools, offices, health facilities, hotels and other busy places, it has been proven that there is a reduction in complaints of dizziness, sneezing, irritation, fatigue with the presence of scented indoor plants in the USA. People can feel more comfortable staying in a place with scented plants (LaCova-Bhat, 2017). Similar results are supported by field observations (Ataee et al., 2017) using colourful plants, and flowering plants.

However, it needs attention, there is a type of plant that actually has a negative effect. *Hoya compacta* is a common house indoor plant in the USA known as wax plant. Horticultural workers studied at the Odense University Hospital did not previously experience respiratory allergies, but in the presence of the plant there were cases of hypersensitivity resulting in rhinitis, rhino conjunctivitis, and respiratory symptoms (Sherson et al., 2017).

3.4 Phytoremediation

Indoor phytoremediation includes the restoration of air quality, which is polluted by substances emitted from buildings and the activities of their users. Physical pollutants include parameters of temperature, humidity, noise. Chemical pollutants include inorganic and organic substances. Microbial contaminants are microscopic living things. Particulates are solid particles, which are separated from physical contaminants, because they contain chemicals and microbes. The level of these pollutants, combined with human response, can produce building environmental conditions that display unhealthy symptoms for occupants, commonly referred to as sick building syndrome (SBS) (H. Samudro et al., 2022a; Almutairi et al., 2019; Nduka et al., 2018).

Physical pollutants come from lighting, kitchen equipment, TV and/or radio entertainment facilities, people's conversations, and various activities in functional spaces. In summary, the progress of indoor phytoremediation research results on physical pollutants is presented in Table 1.

Table 1: Summary of indoor phytoremediation results on physical pollutants

Physical parameters	Plants	Air quality effect
Temperature	Bird's nest fern (*Asplenium nidus* Linn.), which has a high transpiration rate and is easy to grow indoors. (T.-H. Kim et al., 2018; Su & Lin, 2015).	Cooling effect
Humidity	Ditto	Moisturizing
Noise	*Sansevieria trifasciata* and *Scindapsus sp*. (Mediastika & Binarti, 2013).	Silence effect

Chemical pollutants are emitted by most of the building infrastructure (Shen et al., 2020). It includes sanitation infrastructure, deterioration and/or degradation of building materials, furniture, lighting, burning fossil fuels in garage activities, anaerobic decomposition of wet waste and/or foodstuffs (Ulens et al., 2014), kerosene heaters, stoves and gas heaters (Tran et al., 2020). In particular volatile organic compounds (VOCs), formaldehyde is emitted from fiberboards, furniture coatings, varnishes, adhesives for wood products, curtains, oil-based paints, electronic devices, disinfectants for floor and clothing cleaners, preservatives, household cleaners, dishwashing liquid, softeners, shoe care, shampoos. cars, candles and carpets (Teiri et al., 2018). Benzene can be found in fuel oils and products such as synthetic rubber, plastics, nylon, insecticides, paints, dyes, resin glues, furniture wax, detergents, and cosmetics (Kuranchie et al., 2019). Toluene is used as a solvent for paints, coatings, rubbers, oils and resins, and can be found in soil, water, and air (Stockwell et al., 2016). Ethylbenzene is present in consumer products such as paints, inks, plastics and pesticides (Kawai et al., 2019). Xylene is used as an additive in fuel oil mixtures (Mohammadyan & Baharfar, 2015), as well as perfumes, cleaning agents, paints and coatings, fabricated goods, and pesticides. In summary, the progress of indoor phytoremediation research results on chemical pollutants is presented in Table 2 and Table 3 for inorganic and organic respectively.

Table 2: Summary of indoor phytoremediation results on inorganic chemical pollutants

Inorganic chemical parameters	Plants	Air quality effect
Carbon dioxide (CO2)	Each plant absorbs CO2, but is distinguished by the type of plant and light intensity. (Karunananda & Abeysinghe, 2019; Gubb et al., 2018; Sevik et al., 2018; Jatinderjit Kaur Gill & Sharma, 2018; Cetin & Sevik, 2016).	Regulating CO2
	This ability is applied to the absorption of CO2 in the museum space, which when peaks in an enclosed space	Reduce indoor CO2

	produces CO_2 of around 1000ppm (Salvatori et al., 2020). Another proof is to suppress high concentrations of CO_2 during the day and night (Franek & Jarský, 2021).	
Ozon (O_3)	Five common indoor plants (*Peace Lily*, *Ficus, Calathia, Dieffenbachia, Golden Pothos*) were applied (Abbass et al., 2017).	Efficiency depends on leaf area
	Application for *Aspidistra elatior*, *Chlorophytum comosum, Dracaena fragrans, Dracaena marginata, Epipremnum aureus* and *Syngonium podophyllum plants* (Koriesh et al., 2016).	Stimulates the growth of molds in *Epipremnum aureus* and *Dracaena fragrans*

Table 3: Summary of indoor phytoremediation results on inorganic chemical pollutants

Organic chemical parameters	Plants	Air quality effect
Endosulfan pesticide	In the case of spraying for plants for pest elimination, a lot of endosulfan is left in the soil medium (Hwang et al., 2015).	No significant effect on plants
VOCs	Rubber tree, Rhapis, and Happy tree were selected among the plants in the Ficus genus because these plants are cheap, easy to obtain. (Hong et al., 2017; Torpy et al., 2018).	Removes most of the VOCs in the room
	**Chlorophytum comosum* ***Spathiphyllum wallisii* (Suárez-Cáceres & Pérez-Urrestarazu, 2021).	*Efficient elimination, **Inefficient elimination
	Wall-typed plants (C. H. Lee et al., 2015b, 2015a; Wannomai et al., 2019).	Elimination
	Dracaena sanderiana dan *Epipremnum aureum* (Jung et al., 2015).	No significant effect on plants
	Aquatic plants watercress (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), and water coin (*Hydrocotyle umbellata*) (Park & Lee, 2020).	These plants have the ability equivalent to soil plants
	Various types of native potted plants: Eugenia sp., Scindapsus pictus, *Schismatoglottis sp., Tradescantia pallida, Piper porphyrophyllum, Reginula alocasia, Ledebouria sosialis, Peperomia sp.* and *Ledebouria petiolata*. The determining factor is the leaves of the plant. (Noor & Ahmad, 2020).	Indoor air purifier

	Epipremnum aureum has the potential to absorb VOCs (Roi-et & Chaikasem, 2021).	It can be used as passive sampling
Formaldehyde	Various plants (Teiri et al., 2018).	Efficient elimination
	Schefflera actinophylla, Cordyline terminalis and *Dodonea viscosa* (El-Mo et al., 2018).	Efficient elimination
	Wall-typed plants (C. H. Lee et al., 2015b, 2015a).	Inefficient elimination
	Taraxacum mongolicum Hand-Mazz wild. and *Plantago asiatica* L. in the root zone (Zhao et al., 2019).	Efficient elimination
Benzene	For four common decorative plants, *Epipremnum aureum, Chlorophytum comosum, Hedera helix* and *Echinopsis tubiflora*. The determining factors are the transpiration rate and the chlorophyll content of the plant (Gong et al., 2019).	Elimination efficiency is at least 70%
Toluene and xylene	Foliage plants *Fatsia japonica* and *Draceana fragrans.* The removal efficiency of toluene and xylene is determined by the volume of the root zone (K. J. Kim et al., 2014).	Efficient elimination

Buildings are not sterile from microbes (Peccia & Kwan, 2016; H. Samudro et al., 2022b), so their existence needs to be an important concern. The progress of microbial-related phytoremediation is summarized in Table 4.

Table 4: Summary of microbial-related phytoremediation

Microbe parameters	**Plants**	**Air quality effect**
Abundance, diversity, shift	Generally, indoor plants contribute greatly to the abundance and diversity of indoor microbes. There is a shift in the microbiome where the diversity of bacteria in plants increases significantly but the diversity of fungi decreases (Mahnert et al., 2015). Therefore, plants can support their own needs in improving environmental quality.	Enhancing phytoremediation
Bioremediation	Bacteria in plant growing medium (Gunasinghe et al., 2021; Russell et al., 2014).	Aromatic VOC elimination

Particulate matter is a small solid and liquid substance that is dispersed in the air. The classification is fine particulate: PM2.5 (diameter size up to 2.5 µm), and coarse particulate: PM10 (diameter size more than 2.5 µm to 10 µm). Fine particulates generally come from burning fossil fuels, so they have a high potential for kitchen activities (Smith et al., 2020). Fine particulates are also produced from cigarettes, building materials, insect repellent, and other household products (Zhang et al., 2019). Particulates become pollutants, when the concentration of PM2.5 in the room is more than 12 µg/m3 (Xing et al., 2016). Meanwhile, coarse particulates generally come from the deterioration of building materials, dust from occupant activities, and combustion residues, generally kitchen activities. In summary, the progress of indoor phytoremediation research results on particulate pollutants is presented in Table 5.

Table 5: Summary of indoor phytoremediation results on particulate pollutants

Air quality parameters	Plants	Plant specificity	Air quality effect
PM10 and PM2.5	*Diffenbachia amoena* (C. H. Lee et al., 2015b).	Leaf (Gawrońska & Bakera, 2015).	Elimination efficiency about 70%
	Twenty one local plants (B.-K. Jang et al., 2021).	Leaf area	Elimination
		Leaf area, long linear shape, do not overlap (Jeong et al., 2020).	High elimination
		Leaf factor confirmed by 11 other plant species (Kwon, Kwon, et al., 2021).	
	Ardisia crenata, Ardisia japonica, and *Maesa japonica* (Kwon, Kwon, et al., 2021; Kwon, Odsuren, et al., 2021).		Elimination
	Kerria japonica, Sophora japonica, Philadelphus pekinensis, Gleditsia sinensis, and Prunus persica (Chen et al., 2017).	Ineffective for other pollutants	Elimination
	Dieffenbachia amoena and *Spathiphyllum spp*. (Stapleton & Ruiz-Rudolph, 2018; Kwon & Park, 2018).	Adequate indoor light intensity	High elimination
PM2.5	*Epipremnum aureum* (Cao et al., 2019).	Rough and grooved leaf surface	Optimal elimination

However, it needs attention, there are types of decorative plants that are actually toxic to humans. Cases of poisoning by *Nerium oleander* provide clinical features including gastrointestinal, cardiovascular and central nervous system effects. Clinical symptoms are characterized by nausea, vomiting, drooling, colic, diarrhea, ventricular tachycardia, dysrhythmias, heart block, ataxia, drowsiness, muscle tremors (Radenkova-Saeva & Atanasov, 2014). Also, there has been a case of the plant *Echinopsis oxygona*, known as the Easter Lily cactus, being infected with a pathogenic fungus (Ogórek et al., 2021).

4. DISCUSSION

4.1 Progress status

The use of decorative plants related to indoor air quality has grown in number and types, and their remediation function has developed in various tropical and non-tropical areas around the world. Although it has not touched all indoor activities, the progress of human response to the presence of indoor decorative plants has reached activities, which have a long stay of more than 3 hours continuously in the room. Schools, offices, health facilities, and residences. In fact, the coverage of humans starts from children to the elderly, with normal physical conditions to people with disabilities. The scope of the place and people are representative enough to state that decorative plants are an essential living structure in indoor spaces. It is undeniable that there is a type of decorative plant that gives a negative response, it is a special concern to avoid its use.

The essence of indoor decorative plants, which are positive for humans, can be judged from two aspects. First, the nature of plant life is the ability to carry out the processes of respiration and photosynthesis, which other living things do not have. The process of plant respiration requires oxygen and produces carbon dioxide all the time. The process of photosynthesis, although limited to light days, is capable of absorbing more carbon dioxide than it produces, and producing more oxygen than it needs. In balance, these processes produce oxygen, which can be utilized by humans and other living things. Second, in line with the absorption of carbon dioxide, and coupled with sufficient water, plants absorb various other substances, including indoor pollutants. In fact, many types of plants have been shown to be able to remediate various pollutants, whether physical, chemical, microbial, and particulate. The existence of types of plants that are toxic to humans, it is a special concern in its implementation.

4.2 Implementation strategies and tactics

Within the framework of placing decorative plants on positive human response and indoor phytoremediation capabilities, the authors propose strategies and tactics in Table 6. The list may not be complete, but at least it can be a starting point for the promotion of decorative plants for indoor. Several implementations of tactics have been carried out, in mapping (Mangkoedihardjo & Santoso, 2022; Santoso & Mangkoedihardjo, 2013), design (H. Samudro, 2020) and operation works (Jaya et al., 2022; G. Samudro & Mangkoedihardjo, 2020).

Table 6: Framework for strategies and tactics in promoting decorative plants

Strategies	Tactics
Human preferences	1. Prioritizing local wisdom of plant species
	2. Horticultural education for children and home families
	3. Indoor management of non-residential activities
	4. The indoor architectural design of the building actively involves potential users

Phytoremediation ability	1. Collaboration of architects and environmental engineers in building design for the determination of indoor volume and plant species
	2. Identify indoor spaces, which have the potential to emit pollutants
	3. Plot the spaces, which have the potential to cause sick building syndrome (SBS)
Certification	1. SBS potential certificate for building design
	2. SBS potential certificate for constructed building

5. CONCLUSION

An important understanding has been obtained about decorative plants, which can provide a positive response to their inhabitants, and it is important to avoid the use of plants that have a negative effect. Likewise, it has been widely proven that many plants are capable of improving the quality of the indoor environment, even though there are plants that are counterproductive. The advancement of plant applications as a way of healthy indoor buildings encourages phytoarchitecture as contemporary arts and technology based on nature, and therefore results in sustainable indoor uses. Strategies and tactics to promote phytoarchitecture can be implemented according to local conditions.

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7. Competing interests

The authors declare no potential conflict of interest affecting this work.

8. Authors' contributions

HS: conception, design, acquisition of data, analysis and interpretation of data, drafting the manuscript, and revising it, focusing on human response; GS: as did HS' contribution, focusing on indoor phytoremediation; SM: as well as the contributions of HS and GS with the addition of implementation strategies and tactics.

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10. Ethical considerations

Ethical issues (including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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